APPLICATION OF NEUTRON ABSORBING MATERIALS TO REDUCE THE PERFORMANCE OF THERMONUCLEAR THREATS

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Abstract

Nuclear and thermonuclear weapons have been an anxiety factor for people for decades and generations. This paper's purpose is to reduce this anxiety by reducing the effect and efficiency of thermonuclear weapons by discussing on a possible projectile and to trigger new ideas on that subject. To achieve this objective, it is determined that thermonuclear weapons' efficiency could be reduce by capturing fast neutrons which are causing the fusion reaction. To benefit from previous studies, FNRs has been selected to search on their fast neutron capturing technologies. Investigated materials are ^{151}Eu, ^{157}Gd, ^{164}Dy, ^{186}W and ^{178}Hf. These materials' cross-sections, their special features and properties has been compared. Most proper material that has been identified is ^{151}Eu due to its high and reliable neutron capture cross-section and ability to create a neutron capture chain reaction. It is proposed, the most efficient compound of ^{151}Eu would be Eu_2O_3, in powder form. Other helpful materials and their usages has been specified. Projectile's inner mechanism and design has been given and one of the possible casing material of the projectile has been defined as tungsten carbide (WC).

KEYWORDS: Thermonuclear weapons, neutron capture, FBR, fusion, control rods.

INTRODUCTION

Nuclear weapons have been a concern for generations. Deterrent effect of nuclear weapons have turned into an anxiety factor for past years. This paper is mainly proposes and intended to take FNRs' and FBRs' control rod materials from a different perspective, and using their decades of developed technology and knowledge on another field, which is defensive technologies on possible thermonuclear threats on the way of Non-Proliferation of Nuclear Weapons and release people's anxiety on these weapons' possible terrifyingly destructive effect.

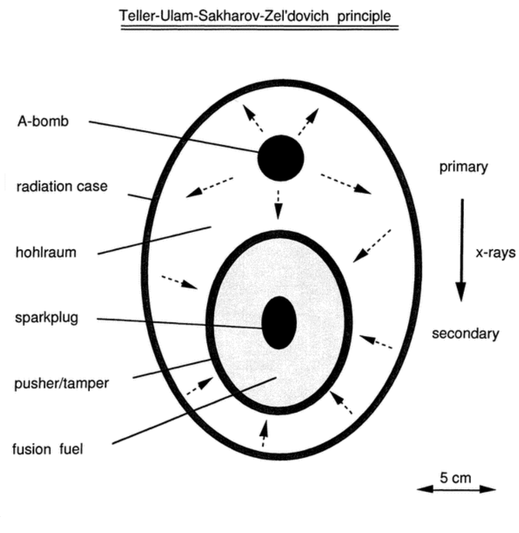
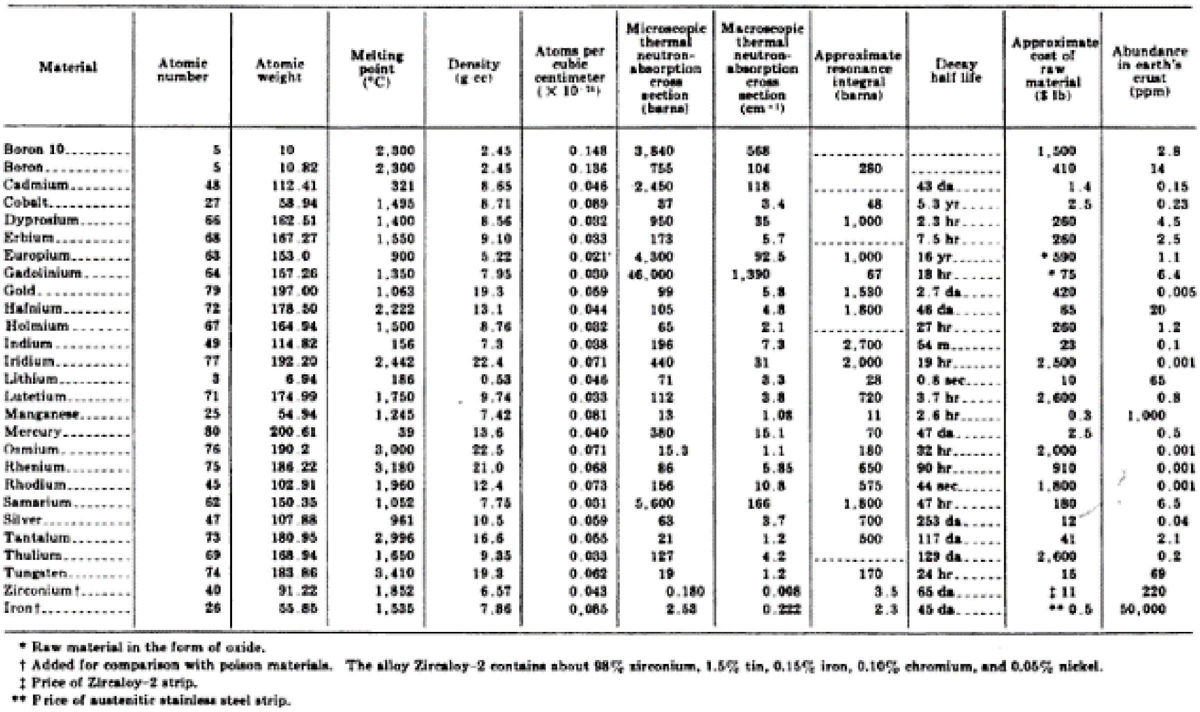


Fig. 1 *Known Teller-Ulam design of a thermonuclear weapon [1].*

Thermonuclear weapons and boosted fission weapons are considered as second generation nuclear weapons, in **Fig. 1** a thermonuclear weapon design is given. A thermonuclear explosion can be investigated in 5 stages: **1)** The high explosives surrounding the core of the primary fire, compressing the fissile material into a supercritical state and beginning the fission chain reaction. **2)** The fissioning primary emits thermal X-rays, which "reflect" along the inside of the casing, irradiating the polystyrene foam. **3)** The irradiated foam becomes a hot plasma, pushing against the tamper of the secondary, compressing it tightly, and beginning the fission chain reaction in the spark plug. **4)** Pushed from both sides (from the primary and the spark plug), the lithium deuteride fuel is highly compressed and heated to thermonuclear temperatures. Also, by being bombarded with neutrons, each lithium-6 atom split into one tritium atom and one alpha particle. Then begins a fusion reaction between the tritium and the deuterium, releasing even more neutrons, and a huge amount of energy. **5)** The fuel undergoing the fusion reaction emits a large flux of high energy (17.6 MeV) neutrons, which irradiates the ^{238}U tamper (or the ^{238}U bomb casing), causing it to undergo a fast fission reaction, providing about half of the total energy. [2]

Stages that we will be working on are stage **4** and stage **5**. Because these are the stages where main neutron reactions happen and lead to fusion which causes the main explosion. In stage **3**, secondary



Material	Atomic number	Atomic weight	Melting point (°C)	Density (g cc)	Atoms per cubic centimeter (× 10⁻²⁴)	Microscopic thermal neutron-absorption cross section (barns)	Macroscopic thermal neutron-absorption cross section (cm⁻¹)	Approximate resonance integral (barns)	Decay half life	Approximate cost of raw material ($ lb)	Abundance in earth's crust (ppm)
Boron 10	5	10	2,300	2.45	0.148	3,840	568	....	....	1,500	2.8
Boron	5	10.82	2,300	2.45	0.136	755	104	280	....	410	14
Cadmium	48	112.41	321	8.65	0.046	2,450	118	....	43 da.	1.4	0.15
Cobalt	27	58.94	1,495	8.71	0.089	37	3.4	48	5.3 yr.	2.5	0.23
Dyprosium	66	162.51	1,400	8.56	0.032	950	35	1,000	2.3 hr.	260	4.5
Erbium	68	167.27	1,550	9.10	0.033	173	5.7	....	7.5 hr.	260	2.5
Europium	63	153.0	900	5.22	0.021	4,300	92.5	1,000	16 yr.	* 590	1.1
Gadolinium	64	157.26	1,350	7.95	0.030	46,000	1,390	67	18 hr.	* 75	6.4
Gold	79	197.00	1,063	19.3	0.059	99	5.8	1,530	2.7 da.	420	0.005
Hafnium	72	178.50	2,222	13.1	0.044	105	4.8	1,800	46 da.	65	20
Holmium	67	164.94	1,500	8.76	0.032	65	2.1	....	27 hr.	260	1.2
Indium	49	114.82	156	7.3	0.038	196	7.3	2,700	54 m.	23	0.1
Iridium	77	192.20	2,442	22.4	0.071	440	31	2,000	19 hr.	2,500	0.001
Lithium	3	6.94	186	0.53	0.046	71	3.3	28	0.8 sec.	10	65
Lutetium	71	174.99	1,750	9.74	0.033	112	3.8	720	3.7 hr.	2,600	0.8
Manganese	25	54.94	1,245	7.42	0.081	13	1.08	11	2.6 hr.	0.3	1,000
Mercury	80	200.61	39	13.6	0.040	380	15.1	70	47 da.	2.5	0.5
Osmium	76	190.2	3,000	22.5	0.071	15.3	1.1	180	32 hr.	2,000	0.001
Rhenium	75	186.22	3,180	21.0	0.068	86	5.85	650	90 hr.	910	0.001
Rhodium	45	102.91	1,960	12.4	0.073	156	10.8	575	44 sec.	1,800	0.001
Samarium	62	150.35	1,052	7.75	0.031	5,600	166	1,800	47 hr.	180	6.5
Silver	47	107.88	961	10.5	0.059	63	3.7	700	253 da.	12	0.04
Tantalum	73	180.95	2,996	16.6	0.055	21	1.2	500	117 da.	41	2.1
Thulium	69	168.94	1,650	9.35	0.033	127	4.2	....	129 da.	2,600	0.2
Tungsten	74	183.86	3,410	19.3	0.062	19	1.2	170	24 hr.	15	69
Zirconium†	40	91.22	1,852	6.57	0.043	0.180	0.008	3.5	65 da.	‡ 11	220
Iron†	26	55.85	1,535	7.86	0,085	2.53	0.222	2.3	45 da.	** 0.5	50,000

* Raw material in the form of oxide.
† Added for comparison with poison materials. The alloy Zircaloy-2 contains about 98% zirconium, 1.5% tin, 0.15% iron, 0.10% chromium, and 0.05% nickel.
‡ Price of Zircaloy-2 strip.
** Price of austenitic stainless steel strip.

Table 1 Neutron poison materials and their properties [3].

fission rod (sparkplug) starts to fission and emits 1-2 MeV neutrons (fission neutrons) and these neutrons will cause Li-6 deuteride fuel (in modern designs) to create tritium.

$$^{6}Li + n \rightarrow \alpha + T$$

Fusion event occurs as the amount of tritium increases by ^{6}Li(n,t)^{4}He - or D(n,abs)T - reactions. Fusion of deuterium and tritium emits high energy neutrons and get hot -which will cause sparkplug to go fission and emit neutrons even at higher flux, which makes this system self-feeding. Then those fast neutrons at ~17 MeV energy cause the ^{238}U tamper to go fission, just like at FBRs.

$$D + T \rightarrow^{4} He + n\,(17.6MeV)$$

$$^{238}U + n(+17.6MeV) \rightarrow f(^{95}Sr +^{140} Xe + 3n + 206.24MeV)$$

The main purpose of this research is to stop the fusion event and by that prevent the further fission of U-238 which means reducing the performance of a thermonuclear weapon. We will be giving examples on popular two staged Teller-Ulam design, as given in **Fig. 1**. The aim is to look at the event theoretically and experimentally for the development of the method. To ensure that the unknown designs and principles about thermonuclear weapons do not matter against the possible method. One of the founded methods to prevent nuclear fusion in these systems is to prevent the production of tritium. As tritium's formation is based on fast neutrons, an appropriate neutron poison that will be placed between lithium deuteride and sparkplug is meant to stop production of fusion reaction's main fuel. So theoretically we can say, to stop a thermonuclear weapon's secondary stage, we can use materials with high neutron capture cross section due to secondary part's action is mainly caused by those fast neutrons.

METHODS and MATERIALS

Since the aim is to stop neutron flux, we must put the external neutron absorber material(s) as going through out fusion fuel, or diffused in it. As our possible target will be falling down from sky with a high speed, best possible method is to use a penetrator projectile to make the interaction between neutron absorber and target's inside. Since the only possible method that seems is using a projectile, we can go through with choosing correct material for that purpose.

In Fast Breeding Reactors it is a critical issue to stop the reaction. Because in FBRs there are no neutron moderators so any neutrons are slowed down and main chain reaction is happening with those fast neutrons (E_n >0.5 MeV), to stop the fission reaction you must use a control rod just like in a regular reactor, but the different thing with FBRs are neutrons, which are more energetic (fast) and fast neutrons are hard to capture by known control rod materials. So it is a discussed and developed issue on FBR control rods, what material should be used? We see that mostly B_4C is preferred in observable FBR examples. But main reason for that is

B_4C is considerably economical than its opponents. Appropriately, we will examine previous researches on fast neutron absorbing control rod materials and review some specific situations and risks that may happen in our usage of these materials.

Commonly used and possible neutron poison materials are given in **Table 1**. The main poison material should be chosen among the ones with highest absorption rates. Which are Gadolinium-157, Boron-10, Samarium-150/151, Europium-151 etc. In the field of absorber materials the main interest indicated in most countries concerns on B_4C, Eu_2O_3 and EuB_6. However the B_4C is the favored absorber material for the present designs and for the near future. On the other hand using Boron would be fatal for our purpose. As our aim is to capture neutrons to keep them away to form tritium, Boron's neutron capture reaction is not a radiative capture, it is mostly a neutron-alpha reaction, $^{10}B(n,a)^{7}Li$, which is ending up with increasing the quantity of Li-7. Unpredicted levels of Li-7 can be incredibly dangerous and risky -as can be seen at Castle Bravo thermonuclear weapon test [2]. ^{7}Li reacts endothermically (-2.46 MeV) with fast neutrons and form tritium as well, so increasing the Li-7 rate means increasing the amount of fusion fuel. Also there are $^{10}B(n,2a)T$, $^{11}B(n,^{9}Be)T$ reactions that can generate tritium as well. Also studies of T. Donomae et al. are showing that the tritium begins to be released from B_4C at 400°C. From the results of this isochronal heating, diffusion coefficients of tritium in B_4C were derived [4]. As a result Boron cannot be used at any parts of the projectile. Which is also forbidding us to benefit from hardness of the B_4C at the further parts of the concept and design.

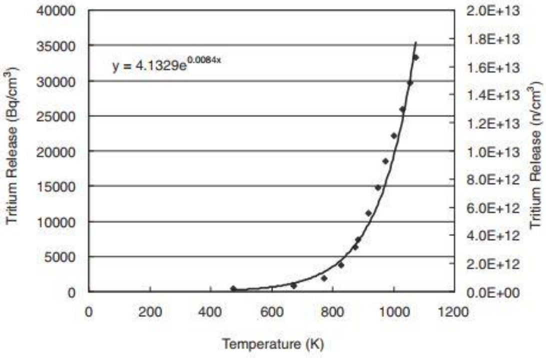


Fig. 2 *Boron's tritium release by temperature [4].*

To compare probable materials' absorption efficiency with cross section of the reaction that aimed to be stopped, following graphs of materials' neutron reactions from JENDL-4.0 library is given.

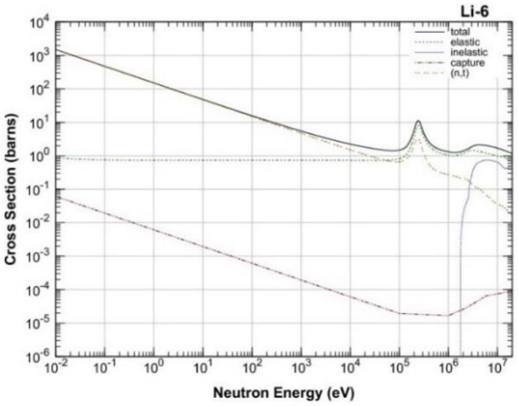
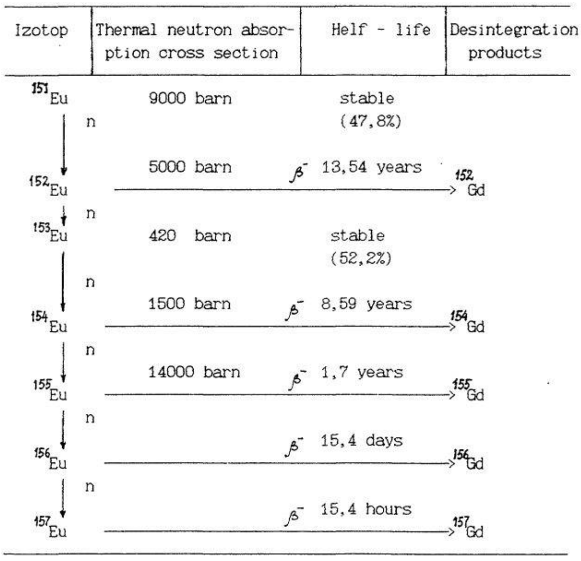


Fig. 3 *Li-6 neutron cross-sections graph (JAEA) [5].*

As it can be seen at **Fig 3**, Li-6 has a higher cross section of both elastic and inelastic scatterings than (n,t) reaction with 1-2 MeV energy neutrons. Which means, it is more likely to Li-6 to act like a neutron moderator than a neutron absorber with fast neutrons. Ideally, this effect will continue until a neutron will get moderated to ~10000 eV energies (Intermediate or lower energy levels). Consequently, in our neutron absorber search we do not have to look for materials that have higher cross sections with neutrons at over 1 MeV energies, than Li-6 has (~0.25 barns). Additionally, Li-6 has a very large region of fitting to 1/v law, with no resonance peaks, making us to choose an absorber material easier.

The lanthanons of most interest as nuclear poisons are europium, dysprosium, samarium, gadolinium, erbium, and holmium. Europium, gadolinium and dysprosium will be examined among them.

Europium



Izotop	Thermal neutron absorption cross section	Helf - life	Desintegration products
^{151}Eu	9000 barn	stable (47,8%)	
^{152}Eu	5000 barn	β^- 13,54 years	^{152}Gd
^{153}Eu	420 barn	stable (52,2%)	
^{154}Eu	1500 barn	β^- 8,59 years	^{154}Gd
^{155}Eu	14000 barn	β^- 1,7 years	^{155}Gd
^{156}Eu		β^- 15,4 days	^{156}Gd
^{157}Eu		β^- 15,4 hours	^{157}Gd

Fig. 4 *Europium isotopes neutron capture chain [6].*

Naturally occurring europium contains 47.77 percent Eu-151 and 52.23 percent Eu-153. Under neutron bombardment, Eu151 yields Eu152, which is an isotope of significant cross section (5,000, barns). Further neutron captures successively produce Eu-153, Eu-154, and Eu-155, all of which have appreciable absorption cross sections. Thus, a chain of four neutron-born daughter isotopes is generated before europium is destroyed as a poison material. **Fig. 4** also presents the thermal neutron absorption cross section of each member of the europium chain, together with abundances and half - lives. These data demonstrate europium to be an extremely long-lived neutron poison [3].

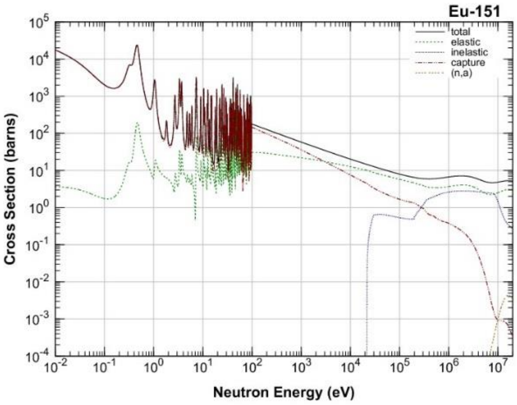


Fig. 5 Eu-151 neutron cross-sections graph (JAEA) [5].

One another important feature of Eu-151 is, its high and reliable cross-sections of elastic scattering. As it is shown at **Fig 5**, between 10^3 and 10^4 eV energy level neutrons, Europium-151 has elastic scattering cross-section between 10-100 barns while at those energy levels Li-6's neutron capture cross-section is between 1-10 barns. This difference may seem little, but it can be evaluated as a potential to keep neutrons "busy" to interact with lithium until the absorbing effect of europium occurs. Chosen europium compound is europium sesquioxide (Eu_2O_3) which is a preferable form for all lanthanons in usage of fast neutron absorbing. Also it is reported in United States Experience with LMFBR Control Material Selection; europium sesquioxide absorbs neutrons without producing gas, the design, performance, and cost of control elements using it would be somewhat more straightforward [7].

Gadolinium

Gadolinium has the highest thermal neutron capture cross-section among all the stable elements, with ~257000 barns. Gadolinium has only two absorbing isotopes, Gd-155 and Gd-157. In contrast with europium these two isotopes are separated by a low cross-section isotope, so that no chain relationship exists. The isotope of mass 155 at an abundance of 14.73 percent has a cross section of approximately 60,000 barns, whereas Gd-157, with an abundance of 15.68 percent, has a cross section of ~257,000 barns. Both of these isotopes undergo (n,y) reactions upon capturing a neutron [3]. The low total abundance of these two isotopes causes the need to enrichment of gadolinium.

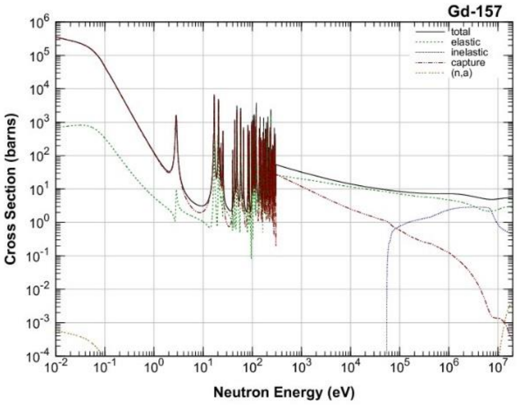
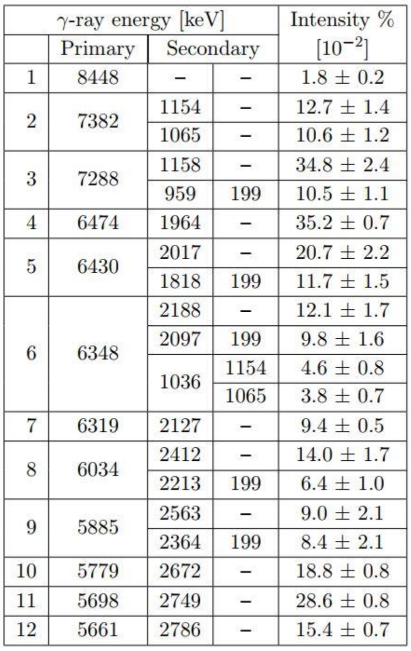


Fig. 6 Gd-157 neutron cross-sections graph (JAEA) [5].

Gadolinium has a lower rate for elastic scattering, at mentioned energy ranges, than Li-6. Thus gadolinium should be used with a moderator. Also gadolinium has one of the highest gamma-ray emitting energies among neutron absorbers. Which can be both considerably dangerous or for benefit of the purpose.

$$\mathrm{n} + {}^{155}\mathrm{Gd} \rightarrow {}^{156}\mathrm{Gd}^{*} \rightarrow {}^{156}\mathrm{Gd} + \gamma \text{ rays (8.536 MeV total), and}$$
$$\mathrm{n} + {}^{157}\mathrm{Gd} \rightarrow {}^{158}\mathrm{Gd}^{*} \rightarrow {}^{158}\mathrm{Gd} + \gamma \text{ rays (7.937 MeV total).}$$



	γ-ray energy [keV]			Intensity %
	Primary	Secondary		$[10^{-2}]$
1	8448	–	–	1.8 ± 0.2
2	7382	1154	–	12.7 ± 1.4
		1065	–	10.6 ± 1.2
3	7288	1158	–	34.8 ± 2.4
		959	199	10.5 ± 1.1
4	6474	1964	–	35.2 ± 0.7
5	6430	2017	–	20.7 ± 2.2
		1818	199	11.7 ± 1.5
6	6348	2188	–	12.1 ± 1.7
		2097	199	9.8 ± 1.6
		1036	1154	4.6 ± 0.8
			1065	3.8 ± 0.7
7	6319	2127	–	9.4 ± 0.5
8	6034	2412	–	14.0 ± 1.7
		2213	199	6.4 ± 1.0
9	5885	2563	–	9.0 ± 2.1
		2364	199	8.4 ± 2.1
10	5779	2672	–	18.8 ± 0.8
11	5698	2749	–	28.6 ± 0.8
12	5661	2786	–	15.4 ± 0.7

Table 2 *Neutron capture gamma-rays energies and intensities of Gd-157 [8].*

If we assume the absorber material which is wanted to be penetrated through inner core of the target, would be in contact with the Pu-239 sparkplug and LiD, these high energy gamma-rays can increase the ratio of sparkplug to go fission than expected. Photofission cross-sections of Pu-239 at 7.5 MeV is 21±4 mb. Also at 11.0 MeV, the corresponding value is 221±69 mb, which is allowing us to say the cross-section is getting larger as the energy increases [9]. As gadolinium can emit 7.5 MeV and higher energy gamma-rays with intensities that are given at **Table 2**, gadolinium gamma-rays can cause Pu-239 sparkplug to burn-up faster than expected, which can cause the whole fusion reaction to fail, which has happened like at The Castle Koon, depending to a small flux of neutrons from primary allowed the secondary to go heated prematurely, and the whole fusion process got failed [2]. Or what is aimed with neutron bombs as anti-ballistic missiles: The burst of neutrons released by an ER weapon can induce fission in the fissile materials of primary in the target warhead. The energy released by these reactions may be enough to melt the warhead, but even at lower fission rates the "burning up" of some of the fuel in the primary can cause it to fail to explode properly, or "fizzle" [10]. Again if we come back to the neutron absorption performance of the gadolinium, it would be the best to use it with an external neutron moderator. The ideal compound for this process of gadolinium is also sesquioxide form of gadolinium, gadolinia (Gd2O3). Also absorber compounds are more efficient in nanostructures than microstructures, as given in **Fig. 7**, which is a property that can be applied for all absorbing material compounds [11].

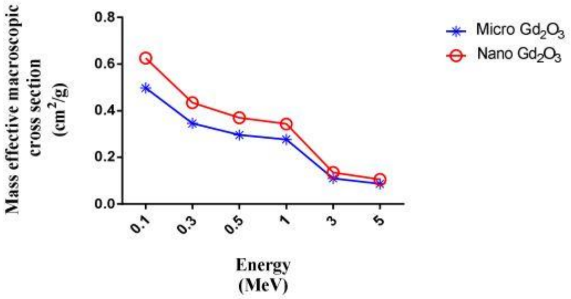


Fig. 7 Changes in mass effective macroscopic cross-section of the gadolinium compound. Nanostructural compounds' efficiencies also can be seen with different materials' graphs [11].

Dysprosium

Dysprosium-164 has lower thermal neutron capture cross-section than gadolinium and europium (~2100 barns), dysprosium's attractive property is its high resonance peaks of both elastic scattering and absorption with the 10^2 to 10^4 energy range neutrons, as it can be seen at **Fig 8.**

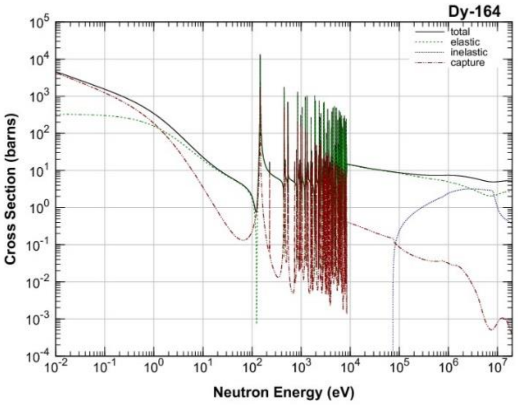


Fig. 8 Dy-164 neutron cross-sections graph (JAEA) [5].

In general, we don't see such high thermal neutron capture cross-sections with non-lanthanide elements but some of their resonance peak values are intimidating for our purpose.

Tungsten

Tungsten-186 has much lower thermal neutron capture cross-section than elements that are given above. W-186's interesting property is the same with dysprosium, it has a considerably wide and high neutron capture resonance peaks. As it's told above, we cannot use boron compounds due to its tritium productive properties. Therefore, tungsten compounds, which would be preferably tungsten carbide due to its hardness, can be used at outer shells or as casing material of the projectile as we cannot benefit from boron carbide. But tungsten oxides, which appear in a powder form, can be considered as main neutron poisons as well.

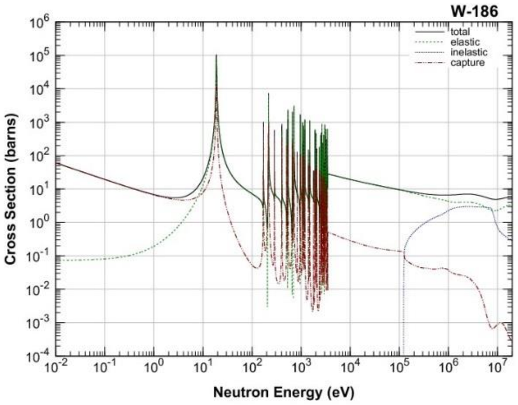


Fig 9 W-186 neutron cross-sections graph. Between 10 and 10^2 energy levels there is a considerably large peak for both capture and scattering process (JAEA) [5].

Hafnium

Hafnium is normally used in a reactor principally as a control rod material. Other possible applications are for use as a flux peak flattener, usually in the form of small pins, strips, or lumps, and as a burnable poison homogeneously distributed in the fuel [3]. The use of a homogeneous kernel made from a mixture of absorbing and moderating materials in control rods of fast neutron nuclear reactors was first proposed in the late 1980s, when “trap” type designs with heterogeneous absorbing and moderating elements were developed. High-tech Research Institute of Inorganic Materials (Moscow) manufactured hafnium hydride pellets, which were irradiated in the BOR-60 reactor. The material demonstrated high radiation resistance and the results of research were included in the monograph “Hafnium in Atomic Engineering”, which in 1993 was published in Russian, and in 2001 in English in the USA. Later in Japan, computational and experimental studies were carried out under the direction of Professor Kanashi, and it was shown that hafnium hydride already containing 50% of the maximum amount of hydrogen (HfH) in hafnium hydride has a physical efficiency of high-energy neutron absorption equal to boron carbide (which is given here to compare, because of its common usage) with 80% enrichment with boron-10 isotopes. Moreover, if boron carbide has boron-10 isotopes that burn out and physical efficiency decreases, then for hafnium hydride over 10 years of operation in a JSFR type fast nuclear reactor, physical efficiency decreases by less than 10%. This is explained by the slowing down of fast neutrons, the presence of resonance absorption region in the intermediate energy range in hafnium, the presence of a chain of daughter isotopes with fairly high neutron absorption cross-sections [12]. Thus, hafnium has a similar cross-section graph with W-186, **Fig. 10**. Hafnium’s preferable compound is hafnium hydride due to its moderation effect.

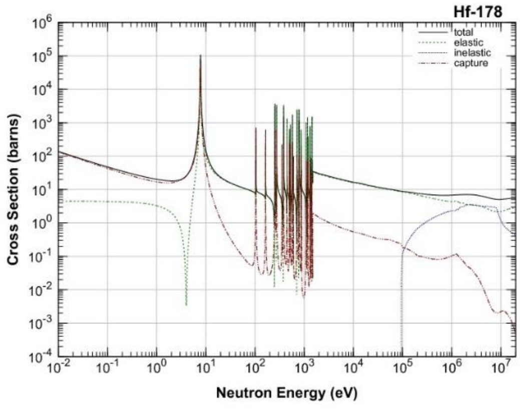


Fig. 10 *Hf-178 neutron cross-sections graph, with a wide and high peak similar to W-186 (JAEA) [5].*

Moderator materials

Most of the absorber materials that are given have higher rate for capturing thermal neutrons, thus with those recommended absorber materials, using moderator materials with them in a compound would be for our good. Metal hydride materials can contain many hydrogen (H) atoms equivalent to those of liquid water. Thus fast neutrons in nuclear reactors are efficiently moderated in the metal hydride. Zirconium hydride has been considered as a neutron moderator in nuclear reactors. In FBR control rod design, rods with zirconium hydrides (ZrH_n) are typically called “trap-type” control rods. It is reported that, the validation of "neutron trap" design using ZrH_2 as a moderator of annular and rod shape as well as absorbers of annular and rod shape to decrease the absorbing material amount in a rod [6]. Which can make our main poison material more efficient. Hafnium hydride also can be used as a moderator due to its properties we mentioned above.

Conclusion of the part

Whole succession of the process and material selection is based on Li-6’s low neutron capture cross-section at neutron energies over 10 MeV and poison material to capture the neutrons at critical energy region which is between 10^3 and 10^4 eV, because Li-6 significantly starts to capture neutrons and form tritium at those energy levels. Thus it can be recommendable to use materials with relatively regular and reliable cross-sections at these range. Therefore europium and gadolinium are more preferable. Also europium is superior to gadolinium because it can form a neutron capture chain because of its neutron-born isotopes that are also showing high capture cross-sections. Although the most preferred material is europium and its sesquioxide compound, other materials that are recommended can still be considered for this task. Using Eu_2O_3 without a metal hydride moderator would be enough because its performance and total neutron reaction is always higher than Li-6, but other materials, especially gadolinium should be used with zirconium hydride compound to achieve a higher efficiency.

DESIGN

This part is mainly about proposing an idea for basic projectile design and mechanism to use the neutron poison material in the most efficient way.

Since the most preferable material Eu_2O_3 appears in a powder form, which is for our benefit, should be in touch with and diffused among the inner parts of the thermonuclear weapon’s secondary (fusion) part, a method like “injection” can be applied. Thus, a model which will act like a syringe and both effective to reach inside of the target and effective in surface area must be done. Created design to achieve this mechanism has been given at **Fig. 11**, which is similar to a “shrapnel shell” design.

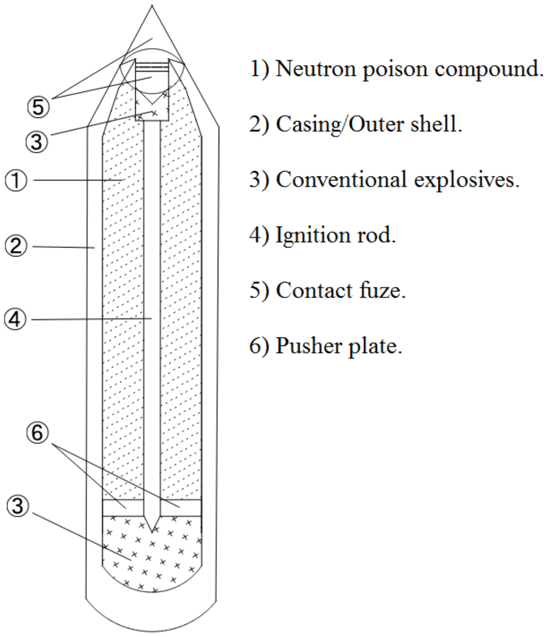
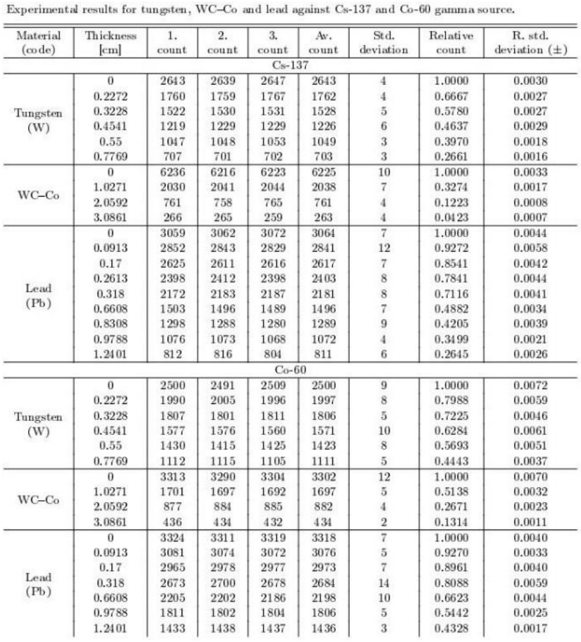


Fig. 11 Drawn design of the projectile with an injection feature for neutron poison compound in powder form.

What is aimed with this design is: When the contact fuze impacts with target weapon, it detonates and burst outs from the projectile to get deeper of the target and cause ignition rod to ignite the conventional explosives/bursting charge, when it detonates pusher plate starts to push the neutron poison material inside of the target. Needing to mention once again, this is just an application idea and a basic design of this idea is presented.

The most recommendable materials for both casing and head of the fuze are tungsten compounds or alloys. Especially tungsten carbide’s hardness and high melting point were effective in this selection, also neutron cross-sections that are given at **Fig. 9** are promising and beneficial for a preliminary neutron capture. One another benefit of tungsten is its properties for gamma-shielding. Gamma-shielding also might be effective to absorbing and reducing the inner radiation pressure. Studies done by B. Buyuk et al [13], and R. Zainon et al [14]. are showing that tungsten carbide can be used to substitute lead as radiation shielding material, as their results can be seen at **Table 3** and **Fig. 12**. These studies also found that tungsten carbide attenuated more radiation compared to pure tungsten, tungsten carbide cobalt and tungsten reinforced basalt fiber. Therefore, it proves that pure tungsten carbide is a good lead-free radiation shielding material.



Experimental results for tungsten, WC–Co and lead against Cs-137 and Co-60 gamma source.

Material (code)	Thickness [cm]	1. count	2. count	3. count	Av. count	Std. deviation	Relative count	R. std. deviation (±)
Cs-137								
Tungsten (W)	0	2643	2639	2647	2643	4	1.0000	0.0030
	0.2272	1760	1759	1767	1762	4	0.6667	0.0027
	0.3228	1522	1530	1531	1528	5	0.5780	0.0027
	0.4541	1219	1229	1229	1226	6	0.4637	0.0029
	0.55	1047	1048	1053	1049	3	0.3970	0.0018
	0.7769	707	701	702	703	3	0.2661	0.0016
WC–Co	0	6236	6216	6223	6225	10	1.0000	0.0033
	1.0271	2030	2041	2044	2038	7	0.3274	0.0017
	2.0592	761	758	765	761	4	0.1223	0.0008
	3.0861	266	265	259	263	4	0.0423	0.0007
Lead (Pb)	0	3059	3062	3072	3064	7	1.0000	0.0044
	0.0913	2852	2843	2829	2841	12	0.9272	0.0058
	0.17	2625	2611	2616	2617	7	0.8541	0.0042
	0.2613	2398	2412	2398	2403	8	0.7841	0.0044
	0.318	2172	2183	2187	2181	8	0.7116	0.0041
	0.6608	1503	1496	1489	1496	7	0.4882	0.0034
	0.8308	1298	1288	1280	1289	9	0.4205	0.0039
	0.9788	1076	1073	1068	1072	4	0.3499	0.0021
	1.2401	812	816	804	811	6	0.2645	0.0026
Co-60								
Tungsten (W)	0	2500	2491	2509	2500	9	1.0000	0.0072
	0.2272	1990	2005	1996	1997	8	0.7988	0.0059
	0.3228	1807	1801	1811	1806	5	0.7225	0.0046
	0.4541	1577	1576	1560	1571	10	0.6284	0.0061
	0.55	1430	1415	1425	1423	8	0.5693	0.0051
	0.7769	1112	1115	1105	1111	5	0.4443	0.0037
WC–Co	0	3313	3290	3304	3302	12	1.0000	0.0070
	1.0271	1701	1697	1692	1697	5	0.5138	0.0032
	2.0592	877	884	885	882	4	0.2671	0.0023
	3.0861	436	434	432	434	2	0.1314	0.0011
Lead (Pb)	0	3324	3311	3319	3318	7	1.0000	0.0040
	0.0913	3081	3074	3072	3076	5	0.9270	0.0033
	0.17	2965	2978	2977	2973	7	0.8961	0.0040
	0.318	2673	2700	2678	2684	14	0.8088	0.0059
	0.6608	2205	2202	2186	2198	10	0.6623	0.0044
	0.9788	1811	1802	1804	1806	5	0.5442	0.0025
	1.2401	1433	1438	1437	1436	3	0.4328	0.0017

Table 3 *Comparison of radiation shielding properties of W, WC-Co and Pb [13].*

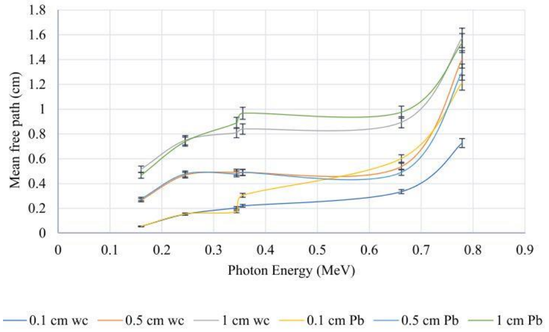


Fig. 12 The mean free path of tungsten carbide (WC) and lead (Pb) at different energies [14].

Tungsten’s preferable compound is tungsten carbide due to its both hardness and carbon atoms’ efficiency for moderating neutrons due to its low mass. Moderating effect of carbon can be calculated with the given formula:

$$\xi = \ln\frac{E_0}{E} = 1 + \frac{(A-1)^2}{2A}\ln\left(\frac{A-1}{A+1}\right)$$

Which can be found, energy decrement value for carbon is 0.1589. When it is compared to hydrogen, 21,92% can be found, which makes it a good moderator material, as we can see it as graphite, as a material commonly used in nuclear reactors for moderating neutrons.

CONCLUSION

To reduce the performance of thermonuclear weapons by failing their secondary part by capturing fast neutrons which are making fusion event possible, Eu_2O_3 compound has been chosen as a neutron poison primarily, to be applied in a projectile design which is meant to inject this neutron poison material to making it more penetrative and diffused inside of fusion fuel. Other possible neutron poison compounds and helpful moderating materials are given. Outer shell and the fuze head of the projectile has been chosen as WC due to its hardness, radiation shielding properties and high melting point. With the intention of being explanatory one last time, this is only the idea and design of a "projectile" (and can be called as an “anti-nuclear missile”), developed against nuclear threats, aiming to trigger the starting of more creative thinking in this field and to prevent people's anxiety against these threats.

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